

Using Nitrogen: What is Best Practice?

Keith Cameron, Hong J Di, Jim Moir, Richard Christie and Ron Pellow
Lincoln University & Ravensdown Fertiliser Co-operative Ltd

Introduction

Feed shortages occur in spring because the rate of pasture growth is below the cow demand (Figure 1). Spring pasture growth rate is slow in the South Island because the soil temperature is low and the rate of nitrogen (N) supply from the soil to the plant is also slow.

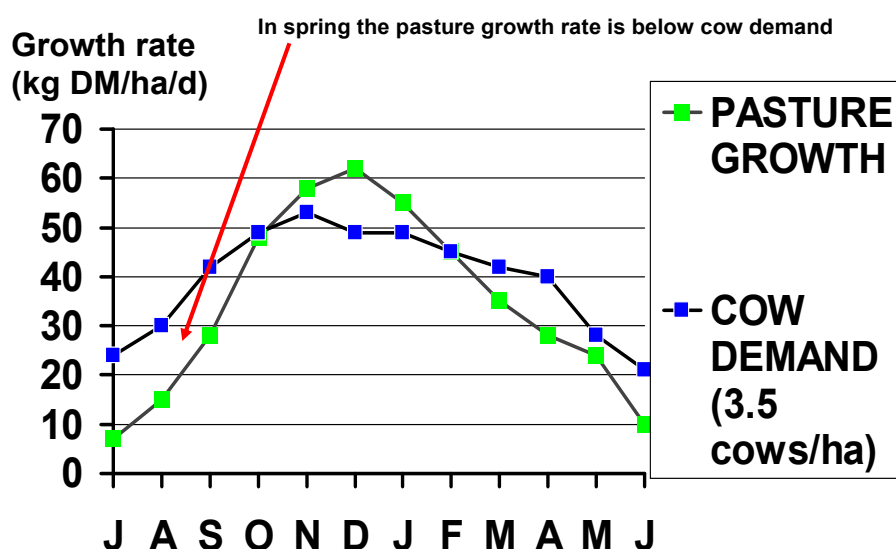


Figure 1: Pasture growth rate in spring is below cow demand.

The rate of nitrogen supply is slow in spring because:

1. Nitrate has been leached from soil in late autumn/winter/early spring,
2. Nitrogen has been lost from the soil as a gas (i.e. by denitrification),
3. The rate of N fixation by clover is slow because of low soil temperatures in the spring (i.e. $< 10^{\circ}\text{C}$)
4. The rate of N mineralisation from soil organic matter is slow because of the low soil temperatures in the spring.

Until recently the only option available to increase the nitrogen supply to pasture plants during the spring was to apply nitrogen fertiliser. However, the development of *eco-n*

nitrification inhibitor technology for pastures opens up a new avenue for increasing the nitrogen supply in spring by reducing the nitrogen losses from the soil over winter.

This paper will discuss best practice use of nitrogen fertilisers and the benefits of using *eco-n* nitrification inhibitor technology.

Economic rate of nitrogen fertiliser to apply

Research has shown that N fertiliser is most efficient when applied between 20 to 40 kg N/ha per application (i.e. giving a production increase of about 12 kg dry matter per kilogram of nitrogen applied). Application rates above 40 kg N/ha will give a smaller increase in dry matter production per kilogram of nitrogen applied and, at 100 kg N/ha, only 7 kg dry matter per kilogram N is achieved (Figure 2).

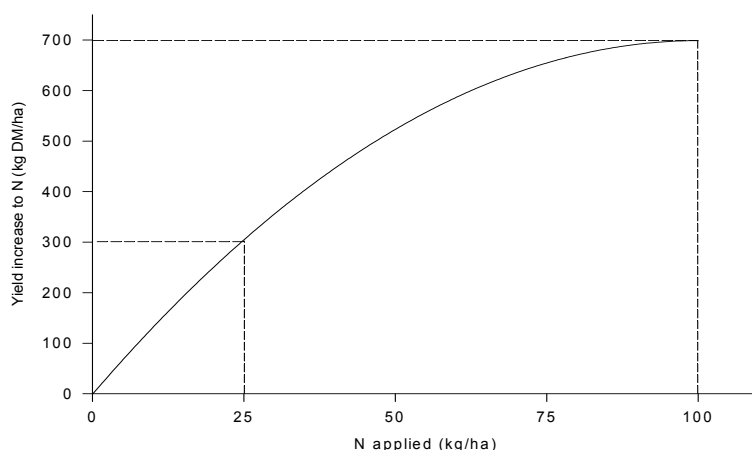


Figure 2: Typical pasture yield response curve to N fertiliser (adapted from Ledgard, 1989).

It is also well established that, in addition to application rates of between 20 – 40 kg N/ha, annual applications of N fertiliser should not exceed 150 to 200 kg N/ha (FertResearch, 1998) in order to reduce the risk of nitrate leaching and associated environmental problems.

Timing of N fertiliser application

It is best to apply nitrogen fertiliser when the pasture cover is between 1,500 to 1,800 kg DM/ha. This ensures that there is sufficient plant leaf area for photosynthesis and thus plant growth to occur. In spring time, it is best practice to apply N fertiliser when the soil temperature (at 10cm depth at 9am) is above 4°C. This will ensure that plant uptake of N occurs. Applying N fertiliser too early in spring (i.e. before soil temperatures are above 4°C) should be avoided because plant uptake is slow and there is a high risk of nitrate leaching. In autumn, the N

fertiliser should be applied before the soil temperature drops below 7°C in order to ensure that plant uptake occurs. Late autumn application when soil temperature is below 7°C should be avoided because of poor plant uptake and the risk of losing the fertiliser by leaching.

The size of the pasture response depends on the time of application and the soil/pasture/climatic conditions. Results from trials in the South Island show that the best response is generally obtained in the spring, with lower response efficiency in the autumn (Table 1).

Table 1: Pasture responses to N fertiliser (kg DM/kg N) applied at 25 – 35 kg N/ha (Ledgard, 1989; and Moir et al. 2003).

District	Time applied	Average response (kg DM/kg N)	Range
Canterbury irrigated	August	15	10 - 15
	Aug/Sept	17	
	Annual	10	7 - 17
Coastal Otago	Early September	13	5 - 30
	March	9	6 – 13
West Coast	Early September	12	9 - 20
	March	10	6 – 18
Southland	Early September	12	8 – 15
	Late February	12	6 - 24

Type of N fertiliser

Research shows that there is little difference in pasture response between Urea and Ammonium fertilisers (Ball and Field, 1982).

Table 2: Pasture response (kg DM/kg N) to three different forms of N fertilisers (Ball and Field, 1982).

Form	Pasture yield (kg DM/ha/y)	Response efficiency (kg DM/kg N)
Urea	13,800	13.9
Ammonium sulphate	13,500	13.1
Ammonium nitrate	13,600	13.3
No fertiliser	8,800	

The choice therefore comes down to cost and the need for sulphate to correct a sulphur deficiency in the soil. If sulphur is not needed, then urea is the cheapest form of N fertiliser available.

Although ammonia gas may be lost from urea fertiliser, research has shown that this loss is relatively small (c. 12%) when urea is applied at 30 kg N/ha to pasture soils (Black et al. 1985; Figure 3). Research has also found that the ammonia volatilisation loss can be reduced to insignificant levels (less than 1%) by applying the urea fertiliser in the rain, or by irrigating soon after application (Black et al. 1987), this is therefore the best practice to follow.

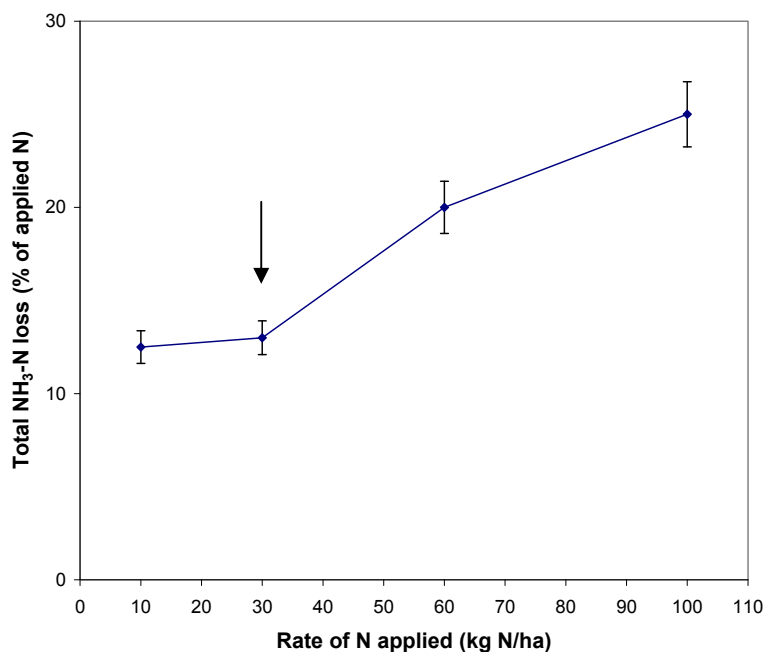


Figure 3: Effect of urea application rate on the percentage of applied N lost by volatilisation. Bars represent standard errors (adapted from Black et al. 1985).

Fertigation

Applying nitrogen fertiliser with irrigation water (called ‘fertigation’) has been used successfully in horticulture, but until recently this has not been widely used in dairying. In theory the following benefits may be captured, however, further research work is required to quantify them under NZ dairying conditions:

- Precision control of the time and rate of application of nitrogen fertiliser. This could ensure pasture responses are maximised.
- Reduced cost of application of urea through the irrigator compared to a contractor’s fertiliser truck.
- Improved application uniformity of nitrogen fertiliser.
- Reduced risk of ammonia volatilization loss from urea (due to immediate washing of urea into the topsoil).
- Potential agronomic gains through more frequent urea applications.

New opportunity to use *eco-n* nitrification inhibitor technology

The nitrogen cycle in grazed pasture systems is known to be 'leaky' with excessive amounts of nitrogen being deposited in animal urine patches causing leaching losses of nitrate, and also emissions of nitrous oxide gas (a powerful greenhouse gas) (Figure 4). Both of these reactions are considered undesirable because they not only represent a loss in soil fertility (and therefore higher costs in applying more fertiliser) but are also increasingly being targeted as major sources of environmental pollution.

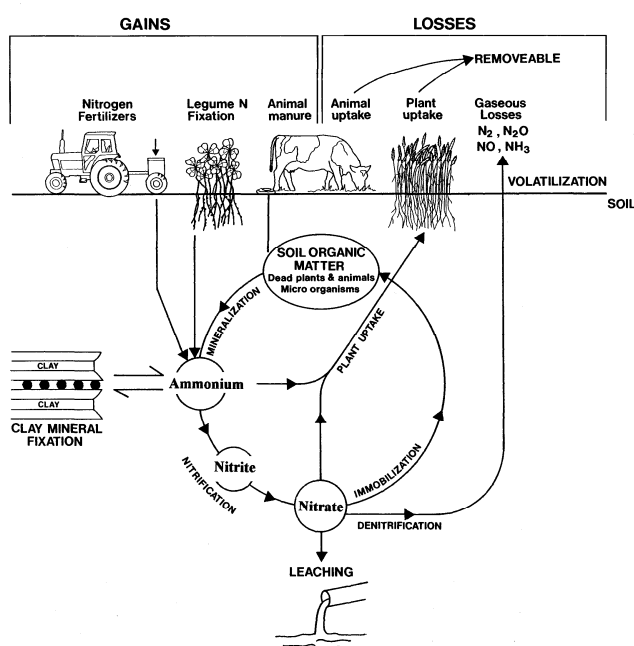


Figure 4: The nitrogen cycle in grazed pasture systems (from McLaren and Cameron, 1996).

The development of *eco-n* nitrification inhibitor technology by Lincoln University and Ravensdown Fertiliser Co-operative Ltd represents a new way of managing the nitrogen cycle to provide more soil nitrogen to meet plant demand, especially in the Spring. This innovation enables us to progress from simply applying more nitrogen fertiliser to meet this shortfall, to improving the efficiency of the soil nitrogen cycle by reducing the 'leaks' from the soil.

Nitrate leaching from dairy farming is a major environmental concern because a high nitrate concentration in drinking water is potentially harmful to humans and livestock, and elevated nitrate concentrations in surface waters may cause pollution which in turn affects recreational use of rivers and lakes (Cameron et al. 2002; Di & Cameron 2002a). It is now widely accepted that in a grazed pasture system direct leaching losses of nitrate from applied fertiliser nitrogen (N), or farm dairy effluent (FDE), are relatively small compared to the large leaching losses that occur from animal urine patches (Scholefield et al. 1993; Di et al. 1998, 2002a; Silva et al. 1999; Ledgard et al. 1999; Di & Cameron 2002b; Monaghan et al. 2002).

Di and Cameron (2002c, 2003, 2004a,b,c) recently reported a series of trials showing the effectiveness of treating grazed pasture soils, including animal urine patches, with a nitrification inhibitor (*eco-n*) to reduce nitrate leaching from a free-draining shallow stony Lismore soil and a deep sandy Templeton soil.

The nitrification inhibitor slows the first stage of nitrification and reduces the rate at which ammonium is converted into nitrate in the soil. Ammonium (NH_4^+) is adsorbed onto the negatively charged cation exchange sites on soil clays and organic matter, thus protecting it from leaching, and allowing it to be taken up by plants. However, nitrate (NO_3^-) is easily leached from the soil because it has a negative charge and is not held by the negatively charged sites on the clay and organic matter. Therefore reducing the rate of conversion from ammonium to nitrate can help to retain more nitrogen in the soil for plant use.

Our recent results show that reductions in nitrate leaching of 60% can be achieved in grazed pasture systems with two applications, i.e. one in the autumn (May) plus a repeat application in the spring (Aug) (Figure 5).

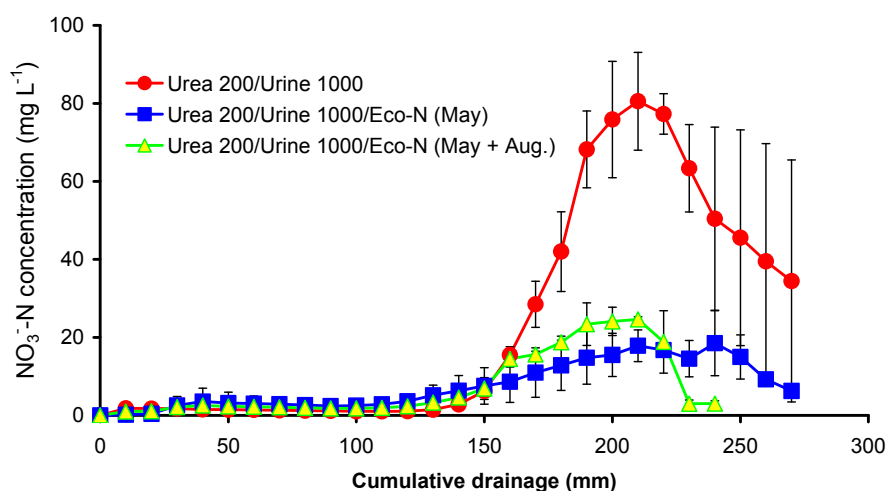


Figure 5: The effect of *eco-n* applied in May plus August on the nitrate concentration in drainage water from below cow urine patches applied in May (Templeton soil) (Di and Cameron, 2004b).

The effect of *eco-n* on the concentration of nitrate in the drainage water from large-scale grazed field plots on Temuka soil at the Lincoln University dairy farm is shown in Figure 6. The nitrate concentration in the drainage water from the *eco-n* treated plots is consistently below that from the controls.

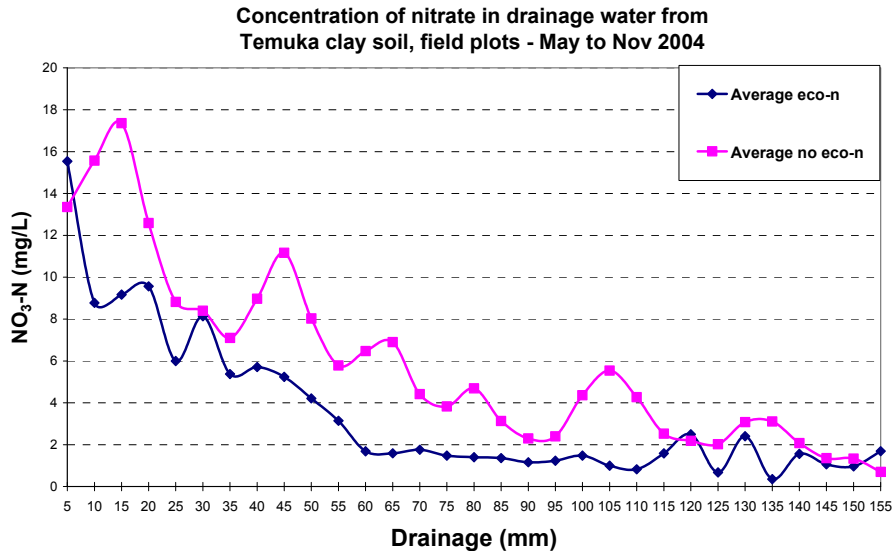


Figure 6: Nitrate concentration in drainage water between May and November 2004 (Cameron et al. 2005a).

Application of *eco-n* has been found to reduce the leaching losses of calcium, magnesium and, in some soils, potassium by about 50% (Di and Cameron, 2004a). This is because when nitrate ions are being leached from the soil they are usually accompanied by calcium, magnesium and/or potassium ions. Since *eco-n* reduces the amount of nitrate that is leached this in turn reduces the amount of calcium, magnesium and/or potassium that needs to be leached with it.

The use of *eco-n* has also been shown to reduce nitrous oxide (N_2O) emissions by 75% (Figure 7). This means that not only is there more nitrogen retained in the soil for plants to use but there is less greenhouse gas emitted from pasture soils. Nitrous oxide is a powerful greenhouse gas and reducing its emissions helps New Zealand meet its commitments to the Kyoto protocol.

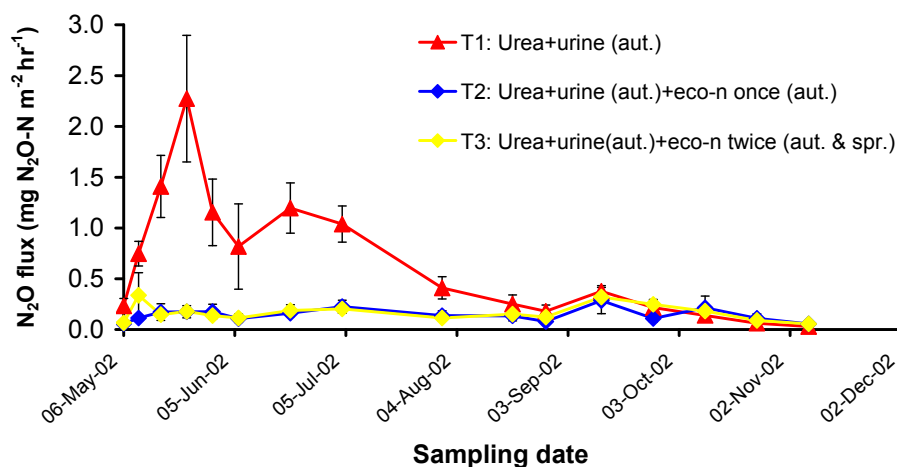


Figure 7: The effect of *eco-n* on nitrous oxide emissions from urine patches (Di and Cameron 2003).

Pasture yield increases occur with the use of *eco-n* technology because significantly more plant-available nitrogen remains in the soil for the plant to use (Cameron et al. 2004). There is understandably some variability in the pasture yield data, similar to the variable responses to nitrogen fertilisers, but whole paddock measurements under dairy grazing on a poorly drained Temuka soil show annual production lifts of 10% to 15% can occur (Figure 8).

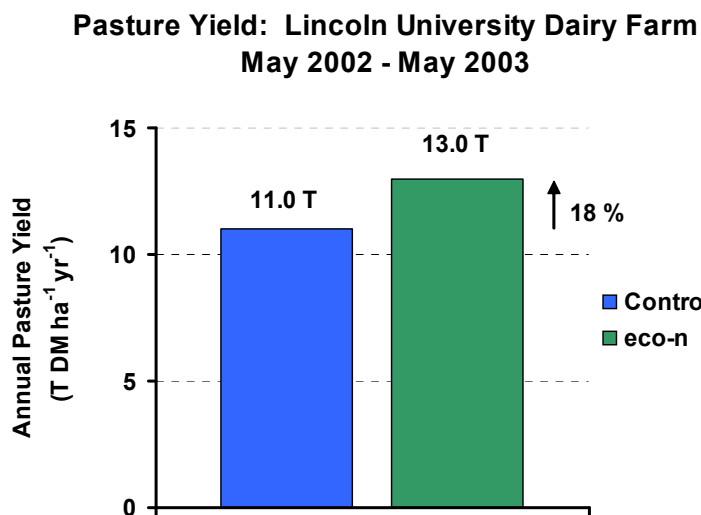


Figure 8: Increase in pasture production due to *eco-n* application under dairy grazing on a Temuka soil (Cameron et al. 2005b).

Plant responses in the spring have been very significant, with increases of over 20% being recorded on the Lincoln University dairy farm grazed pasture plots (Figure 9). Increased pasture production is being achieved between urine patches as well as from within the urine patches (Figure 9). This extra growth in the spring is particularly valuable and has been recorded each year for the past three years.

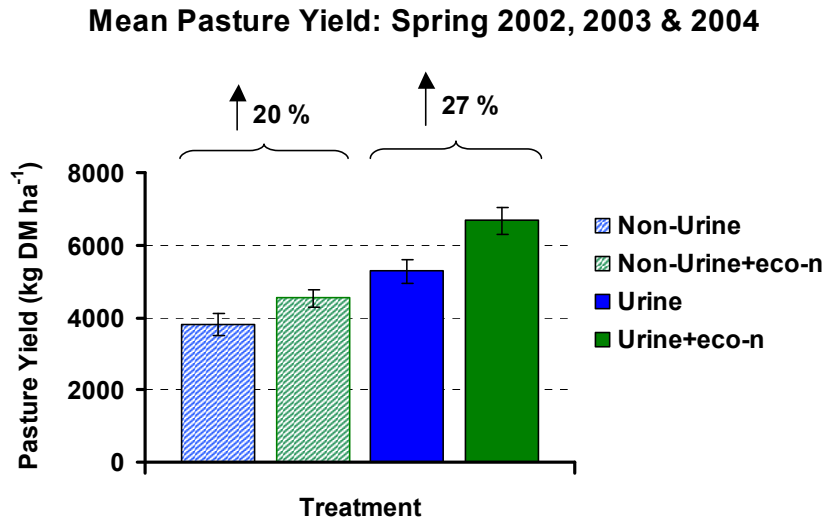


Figure 9: Spring pasture response to *eco-n* applied in May and August.

Detailed plant analysis work has found that the pasture grown with *eco-n* is of equally high quality with similar ME levels (Figure 10) and similar crude protein levels (Figures 11). Pasture composition (in particular clover content) is similar in *eco-n* and control treatments. Clover content typically reaches 50% in these pastures in the spring.

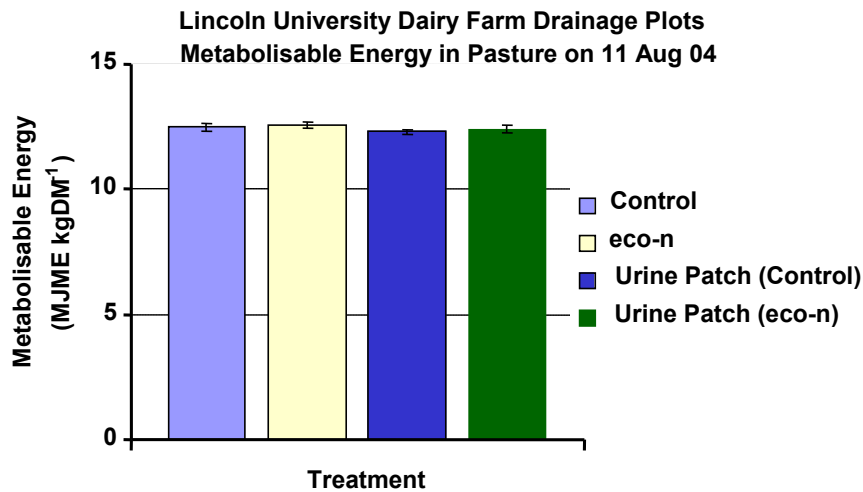


Figure 10: Pasture grown with *eco-n* is equally good quality.

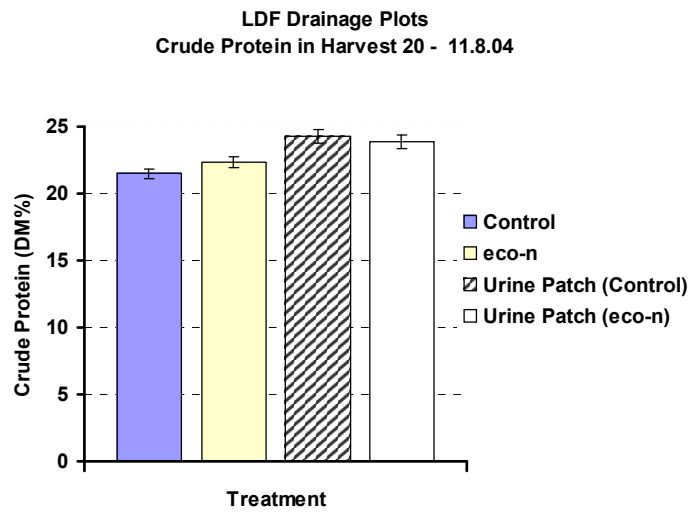


Figure 11: Crude protein levels in *eco-n* treated pasture were not significantly different.

Plant analysis also reveals that the use of *eco-n* did not affect the magnesium levels in the herbage (Figure 12), nor the herbage concentration of calcium or potassium.

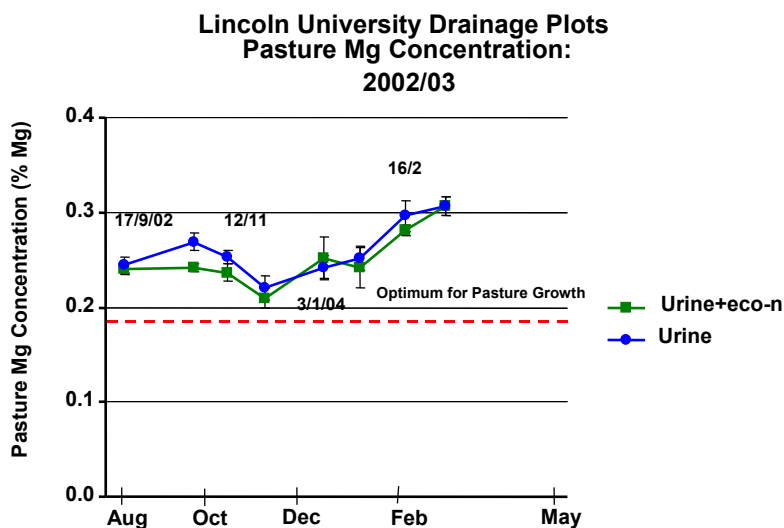


Figure 12: Pasture grown with *eco-n* has a similar magnesium concentration to the non-*eco-n* controls .

These latest results are particularly important because they are derived from large (100 m²) grazed pasture plots that are under normal farm management on the Lincoln University

dairy farm. They therefore represent a successful scaling up from the lysimeter trials and confirm the lysimeter results at the farm scale.

The nitrate concentration in *eco-n* treated urine patch pasture plants was found to be lower than in the non-*eco-n* controls (Figure 13). This occurs because *eco-n* reduces the rate of nitrate production in the soil and therefore the plants take up ammonium for their nutrition rather than nitrate. As shown in Figure 13 the use of *eco-n* has the potential to reduce the nitrate concentration to below ‘toxic levels’; which may help to reduce the risk of ‘nitrate poisoning’.

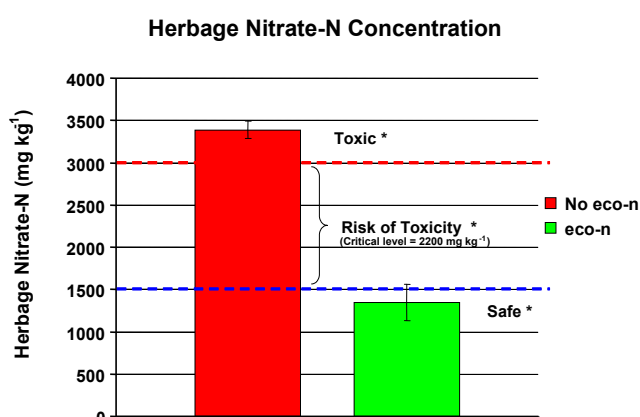


Figure 13: *Eco-n* significantly reduced the herbage nitrate concentration in urine patch areas of annual ryegrass. (The critical level of herbage nitrate is usually taken to be 2,200 mg/kg dry matter, with a risk of toxicity occurring between 1,500 and 3,000 mg/kg depending on conditions.)

Cost effectiveness of *eco-n*

Each application of *eco-n* costs \$62.05/ha as an applied cost, with two applications required per drainage season (or per calendar year). The annual applied cost is therefore \$124.10/ha/year (GST exclusive). Valuing environmental gains at the farm level is difficult but dairy farmers can more easily relate to the value of additional feed grown, as discussed by Christie (2004) and Christie and Roberts (2004).

The research work indicates that when *eco-n* is used to retain more nitrogen in the soil over late autumn/winter/spring that increases of 10-15% in annual paddock pasture production can be achieved. The additional feed produced with *eco-n* can be compared to the cost of purchasing feed, the cost of growing additional feed (typically with urea) or the value gained by converting additional feed into milk production.

Bought in feeds are typically purchased at 15-20 cents per kilogram drymatter (kgDM) while the cost of growing additional feed with urea can range from 10-15 cents per kg DM, depending on the nitrogen response. A 10% annual increase in feed with *eco-n* by comparison would cost 9.5 cents per kg DM while a 15% increase would only cost 6.4 cents per kg DM (assuming current production of 13,000 kg DM per hectare per year). Table 3 summarises the comparative cost of additional feed.

Table 3: Comparative cost of additional feed sources.

Source of additional feed	Cost per kg DM
<i>Eco-n</i> (used as recommended in autumn and winter)	6-10 cents/ kg DM
Urea	10-15 cents / kg DM
Bought in feed	15-20 cents / kg DM

Converting additional feed directly into milk production is the most efficient means of harvesting and valuing the additional feed produced with *eco-n*. At a payout of \$4.00 / kg milksolids, and a typical conversion ratio of 15 kilograms dry matter per kilogram milksolids, a 10% increase in pasture production provides an additional \$347/hectare income. Subtracting the cost of *eco-n* results in a net increase of \$223/ha. A 15% increase as the result of applying *eco-n* will provide a net increase of \$396/ha. (based on 13,000kg DM /ha/year as above). Table 4 outlines the return per hectare from converting additional pasture grown with *eco-n* into milk production.

Table 4: Return on investment with *eco-n* at 10% and 15% increased pasture production¹

	Return with 10% increase in Pasture Production	Return with 15% increase in Pasture Production
Increased pasture production	1300 kg DM/ha/yr	1950 kg DM/ha/yr
Additional Milksolids	87 kg MS/ha/yr	130 kg MS/ha/yr
Total gross return	\$347 /ha/yr	\$520 /ha/yr
Net return	\$223 /ha/yr	\$396 /ha/yr
Return on investment	179%	319%

Note: ¹ (Based on current production of 13,000 kg DM/ha/year and \$4.00 /kg MS)

The sensitivity to increased grass production achieved by *eco-n* (due to the better retention of nitrogen in the soil) can be seen in the different financial outcome for 10% and 15% pasture production increases. At 13,000 kg DM base production, achieving a 10% lift in production with *eco-n* produces additional feed at a lower cost than using urea, or buying in feed at standard market prices. When the farm maximises the conversion of additional feed to

milk solids, both the return per hectare and the return on investment are excellent, even with 10% extra grass growth.

Dairy farmers who produce around 13,000–15,000 kg DM hectare a year and apply *eco-n* can expect increased pasture production. Higher N users (at around 200 kg/ha) and who produce very high pasture yields such as 18,000 kg DM hectare a year should be able to apply *eco-n*, reduce their N inputs, and still have similar levels of pasture production.

When should *eco-n* be applied?

Eco-n should be applied to recently grazed (short) pasture where it can more quickly get into the soil, and receive 10 mm of rainfall or irrigation soon after application to wash it into the soil. Treat in a similar manner to fertiliser by not applying while stock is in the paddock and allowing it to be washed in before regrazing. It is unlikely to have any effect on animals if grazed after application, but its effectiveness will be reduced if it does not reach the soil.

Application in fine particle suspension form is necessary because it is vital to ensure even coverage of the whole grazed pasture soil area. A suspension is used as the most practical way to apply *eco-n*. Timing is very important. The April/May application covers the high-risk leaching period over winter, while the August/September dressing ensures coverage through spring. The product is not persistent over long periods and three to four months of protection per application is achieved.

Ravensdown closely manages the application of *eco-n* through the use of approved spray applicators that can provide proof of placement. This means that the product is sold on a per hectare applied cost basis. Taking this approach allows Ravensdown to ensure that the new product is applied appropriately (at the right rate and time) and on farm types where it will be economically effective. The accurate recording of where all product is applied also allows further studies on a regional and national basis in relation to the environmental benefits, particularly for greenhouse gas inventory calculations.

Using *Eco-n* and Nitrogen Fertiliser

Applying *eco-n* in the autumn and again in the spring results in additional pasture growth, primarily in early spring. Therefore, nitrogen fertiliser should continue to be used in the autumn to provide pre-winter pasture. However, spring nitrogen fertiliser inputs can be reduced, allowing more strategic use of nitrogen fertiliser as required over the remainder of the year.

Conclusions

Until recently the only option available to increase the nitrogen supply to pasture plants during the spring was to apply nitrogen fertiliser. However, the development of *eco-n*

technology opens up a new avenue for increasing the nitrogen supply in spring by reducing the nitrogen losses from the soil over winter.

Nitrogen fertiliser recommendations

- Apply up to 150 to 200 kg N/ha of N fertiliser per year to grazed pasture, depending on the soil type, climate and management.
- Apply up to 40 kg N/ha per application.
- Apply when soil temperature is above 4°C in spring and above 7°C in autumn. (i.e. not too early in spring or too late in autumn).
- Apply when pasture cover is 1,500 - 1,800 kg DM/ha
- and, if possible, leave at least 3 weeks before grazing.

Eco-n nitrification inhibitor technology

The development of *eco-n* nitrification inhibitor technology also opens up an opportunity to decrease nitrogen fertiliser use in the early spring, because the *eco-n* treatment increases the amount of N retained in the soil. Our research results show that the use of *eco-n* on grazed pasture soils can:

- increase spring pasture production;
- increase annual pasture production;
- reduce nitrate leaching;
- reduce cation leaching;
- reduce nitrous oxide emissions (a potent greenhouse gas).

Acknowledgements

We would like to thank Ravensdown Fertiliser Co-operative Ltd., FRST, the Pastoral Greenhouse Gas Research Consortium (PGGRC) and Lincoln University for funding this research project. We would also like to thank Trevor Hendry, Steve Moore and Nigel Beale of Lincoln University for their excellent technical work.

References

- Ball, P.R. and Field, T.R.O. 1982. Responses to nitrogen as affected by pasture characteristics, season and grazing management. In: 'Nitrogen Fertilisers in NZ Agriculture' (Ed. P.B. Lynch). NZIAS, Wellington, pp. 45-64.
- Black A S, Sherlock R R, Smith N P. Cameron K C and Goh K M. 1985. Effects of form of nitrogen, season, and urea application rate on ammonia volatilisation from pasture. New Zealand Journal of Agricultural Research 28: 469-474.
- Black A S, Sherlock R R, Smith N P. 1987. Effect of timing of simulated rainfall on ammonia volatilization from urea, applied to soil of varying moisture content. Journal of Soil Science 38: 679-687.
- Cameron K C, Di H J. 1999. Nitrogen: What is appropriate use? South Island Dairy Event Proceedings (ed. D. Elvidge), p97-105.
- Cameron K C, Di H J and Condron L M. 2002. Nutrient and pesticide transfer from agricultural soils to water in New Zealand. P373-393 in: P M Haygarth and S C Jarvis (Editors) 'Agriculture, Hydrology and Water Quality'. CAB International, Oxon, U.K.
- Cameron K C Di H J Moir J Christie R G and van der Weerden T. 2004. Clean and green with *eco-n*. South Island Dairy Event Proceedings (ed. D. Kilgour) p124-137.
- Cameron K C, Di H J Moir J Christie R G and Pellow R. 2005a. Improved nitrogen management with *eco-n* nitrification inhibitor – an example of growing for good. Intern. Large Herds Conference Proceedings, Christchurch, April 2005 (in press).
- Cameron K C, Di H J Moir J Roberts A Pellow R and Christie R.G 2005b. Treating grazed pasture soil with a nitrification inhibitor *eco-n* to decrease nitrate leaching. Fertilizer and Lime Research Centre Conference Proceedings, Massey University, Feb 2005 (in press).
- Christie R G. 2004. Using the nitrification inhibitor (*eco-n*) on NZ dairy farms. Primary Industry Management Journal 7(1): 38 – 41.
- Christie R G and Roberts A. 2004. Using the nitrification inhibitor (*eco-n*) on NZ dairy farms. Large Herds Conference, 29 March 2004, Napier.
- Di H J, Cameron K C Moore S and Smith NP. 1998. Nitrate leaching from dairy shed effluent and ammonium fertiliser applied to a free-draining soil under spray or flood irrigation. New Zealand Journal of Agricultural Research 41: 263-270
- Di H J and Cameron K C. 2002a. Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. Nutrient Cycling in Agroecosystems 64: 237-256.
- Di H J and Cameron K C. 2002b. Nitrate leaching and pasture production from different nitrogen sources on a shallow stony soil under flood irrigated dairy pasture. Australian Journal of Soil Research 40: 317-334.

- Di H J and Cameron K C. 2002c. The use of a nitrification inhibitor, dicyandiamide (DCD), to reduce nitrate leaching from cow urine patches in a grazed dairy pasture under irrigation. *Soil Use and Management* 18: 395-403.
- Di H J and Cameron K C. 2003. Mitigation of nitrous oxide emissions in spray-irrigated grazed grassland by treating the soil with a nitrification inhibitor, dicyandiamide (DCD). *Soil Use and Management* 19: 284-290.
- Di H J and Cameron K C. 2004a. Effects of the nitrification inhibitor, diacyandiamide on potassium, magnesium and calcium leaching in grazed grassland. *Soil Use and Management* 20: 2-7.
- Di H J and Cameron K C. 2004b. Treating grazed pasture soil with a nitrification inhibitor, *eco-n*TM, to decrease nitrate leaching in a deep sandy soil under spray irrigation – a lysimeter study. *New Zealand Journal of Agricultural Research* 47: 351-361.
- Di H J and Cameron K C. 2004c. Effects of temperature and application rate of a nitrification inhibitor, DCD, on nitrification rate and microbial biomass in a grazed pasture soil. *Australian Journal of Soil Research*. 42: 927-932.
- FertResearch. 1998. Code of Practice for Fertiliser Use. FertResearch, Auckland.
- Ledgard, SF. 1989. Nitrogen Fertiliser Use on Pastures and Crops. MAFTech, Ruakura.
- Ledgard S F, Penno J W and Sprosen M S. 1999. Nitrogen inputs and losses from clover/grass pastures grazed by dairy cows, as affected by nitrogen fertilizer application. *Journal of Agricultural Science, Cambridge* 132: 215-225.
- McLaren RG and Cameron KC. 1996. *Soil Science*, Oxford University Press, Auckland. 302pp.
- Moir, J. L., Cameron, K. C., Di, H. J., Roberts, A. H. C. and Kuperus, W., 2003. The effects of urea and ammonium sulphate nitrate (ASN) on the production and quality of irrigated dairy pastures in Canterbury, New Zealand. In: L.D. Currie (Editor), *Tools for nutrient and pollutant management: Applications to agriculture and environmental quality*. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand.p139-145.
- Monaghan R M, Paton R J and Drewry J J. 2002. Nitrogen and phosphorus losses in mole and tile drainage from a cattle-grazed pasture in eastern Southland. *New Zealand Journal of Agricultural Research* 45: 197-205.
- Roberts, AHC, Morton, J, and Edmeades, DC. 1994. *Fertiliser Use on Dairy Farms*. Dairying Research Corporation and AgResearch. 36p.
- Scholefield D, Tyson K C, Garwood E A, Armstrong A C, Hawkins J and Stone A C. 1993. Nitrate leaching from grazed grassland lysimeters: effects of fertilizer input, field drainage, age of sward, and patterns of weather. *Journal of Soil Science* 44: 601-613.

Silva R G, Cameron K C, Di, H J and Hendry, T. 1999. A lysimeter study of the impact of cow urine, dairy shed effluent and nitrogen fertilizer on drainage water quality. *Australian Journal of Soil Research* 37: 357-69.